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DOE Annual Progress Report: Water Needs and Constraints for Hydrogen Pathways

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Water Needs and Constraints for Hydrogen Pathways

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Project Start Date: October 1, 2007

Project End Date: October 1, 2009

Objectives

- Quantify the impact of water (cost, quality, scarcity) on a future hydrogen economy
- Quantify the impact of a future hydrogen economy on national and regional water resources
- Document best practices for hydrogen stakeholders in system design and feedstock management with respect to water

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior

(D) Feedstock Issues

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 1: Complete evaluation of the factors (geographic, resource availability, existing infrastructure) that most impact hydrogen fuel and vehicles. (3Q, 2005)
- Milestone 5: Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios. (4Q, 2009)
- Milestone 11: Complete environmental analysis of the technology environmental impacts for the hydrogen scenarios and technology readiness. (2Q 2015)
- Milestone 27: Complete the 2nd version of the Macro-System Model to include the analytical capabilities to evaluate the electrical infrastructure. (2Q, 2011)

Accomplishments

- Constructed a spreadsheet model that calculates water withdrawal and consumption for hydrogen process and cooling water from hydrogen process parameters and water supply quality data
- Estimated cost of water management equipment for the four most likely hydrogen production pathways (forecourt and distributed, SMR and electrolysis)
- Calculated economic tradeoff between water use and investment in water-saving technologies by integrating water technology analysis with H2A model
- Working with NREL and Sandia to incorporate water analysis into MSM
- Working with Sandia to incorporate SNL's model of national and regional water resources with hydrogen rollout scenarios

Introduction

Water is a critical feedstock in the production of hydrogen. In fact, water and many of the energy transformations upon which society depends are inextricably linked. Approximately 39% of freshwater withdrawals are used for cooling of power plants, and another 8% are used in industry and mining (including oil and gas extraction and refining). Major changes in the energy infrastructure (as envisioned in a transformation to a hydrogen economy) will necessarily result in changes to the water infrastructure. Depending on the manner in which a hydrogen economy evolves, these changes could be large or small, detrimental or benign.

Water is used as a chemical feedstock for hydrogen production and as a coolant for the production process. Process and cooling water must meet minimum quality specifications (limits on mineral and organic contaminants) at both the inlet to the process and at the point of discharge. If these specifications are not met, then the water must be treated, which involves extra expenditure on equipment and energy. Furthermore, there are multiple options for water treatment and cooling systems, each of which has a different profile of equipment cost and operational requirements. The engineering decisions that are made when building out the hydrogen infrastructure will play an important role in the cost of producing hydrogen, and those decisions will be influenced by the regional and national policies that help to manage water resources.

Approach

In order to evaluate the impacts of water on hydrogen production and of a hydrogen economy on water resources, this project takes a narrowly-scoped lifecycle analysis approach. We begin with a process model of hydrogen production and calculate the process water, cooling, electricity and energy feedstock demands. We expand beyond the production process itself by analyzing the details of the cooling system and water treatment system. At a regional scale, we also consider the water use associated with the electricity and fuel that feed hydrogen production and distribution.

The narrow scope of the lifecycle analysis enables economic optimization at the plant level with respect to cooling and water treatment technologies. As water withdrawal and disposal costs increase, more expensive, but more water-efficient technologies become more attractive. Some of the benefits of these technologies are offset by their increased energy usage. We use the H2A hydrogen production model to determine the overall cost of hydrogen under a range of water cost and technology scenarios.

At the regional level, we are planning on following the hydrogen roll-out scenarios envisioned by Greene and Leiby (2008) to determine the impact of hydrogen market penetration on various watersheds. The economics of various water technologies will eventually be incorporated into the temporal and geographic Macro System Model via a water module that automates the spreadsheet models described above.

Results

At the time of this progress report, the major achievement for FY2009 has been the completion of the framework and analytical results of the economic optimization of water technology for hydrogen production. This accomplishment required the collection of cost and performance data for multiple cooling and water treatment technologies, as well as the integration of a water and energy balance model with the H2A framework.

22 (twenty-two) different combinations of production method (SMR, electrolysis), scale (centralized, forecourt), cooling (evaporative tower, dry) and water treatment (reverse osmosis, ion exchange) were evaluated. The following data were collected: water withdrawal, water discharge, electricity consumption, equipment footprint, equipment cost, installation cost, annual equipment and material costs and annual labor costs. These data, when consolidated, fit into a small number of input cells in H2A. Items such as capital cost end up as line-items for which there is space in the existing H2A spreadsheets. Items such as electricity use are added to the values that already exist in H2A.

Table 1 lists eight potential technology combinations for cooling and water treatment associated with centralized SMR hydrogen production. When water costs are very low, the most economical system is described by row B, however, as water purchase and discharge prices rise, systems with higher water efficiency prevail. Tables 2a, 2b and 2c show the price of hydrogen production as a function of water purchase and discharge price. In table 2a, the technology is fixed. In table 2b, the price is the lowest of the eight available water technology options. Table 2c identifies the chosen technology for the economic conditions.

As can be seen from comparison of tables 2b and 2c, in cases of extreme water strain (very high water purchase or discharge prices) the savings resulting from advanced treatment and cooling technologies can be significant. However, it is worth noting that such high water prices are exceedingly rare at this time.

Conclusions and Future Directions

This analysis has shown that at current prices, water is not expected to have a major impact on hydrogen deployment. In previous years' work, it was shown, qualitatively, that acquisition of water rights (permitting) can present a major issue for any new water user, particularly in highly water stressed areas. However, because water rights are complex and contentious, further quantitative analysis of this hurdle was not pursued. Instead, a methodology for placing an upper bound on hydrogen price with respect to water (ie. minimization of water use and discharge through advanced technology) was developed. This methodology resulted in the economic optimization described above.

In the remaining months of this project, the following tasks will be completed:

- Calculate regional water impacts over time with the projected hydrogen rollout scenarios proposed by Green and Lieby (2008)
- Work with Sandia to incorporate SNL's model of national and regional water resources with hydrogen rollout scenarios
- Work with NREL and Sandia to incorporate water analysis into MSM

FY 2009 Publications/Presentations

1. Simon, A.J. "Water's Role in a Hydrogen Economy", presentation to the Fuel Pathways Integration Technical Team (FPITT), March 18, 2009. Washington, DC.

2. Simon, A.J., “Water’s Impacts on Hydrogen”, presentation to the DOE’s Annual Merit Review, May 19, 2009. Alexandria, VA.

References

1. Greene, D.L et. al. “Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements.” Oak Ridge National Laboratory, March 2008.
2. White, R.G. “Water Needs and Constraints for Hydrogen Pathways” part of the 2008 DOE Hydrogen Technologies Annual Progress Report.

Acronyms

H2A	Doe’s Hydrogen Produciton and Delivery Models
NREL	National Renewable Energy Laboratory
SMR	Steam Methane Reforming
SNL	Sandia National Laboratory

Figure Captions

- Table 1. Cooling and Water Treatment Technologies for Central SMR Hydrogen Production
Table 2a. Hydrogen Costs vs. Water Purchase and Discharge Costs – Fixed Technology
Table 2b. Hydrogen Costs vs. Water Purchase and Discharge Costs – Optimum Technology
Table 2c. Optimum Technology vs. Water Purchase and Discharge Costs

Table 1:

Treatment Systems Analyzed			
	Cooling Technology	Water Treatment Technology	Water Discharge
A	Cooling Tower	Ion Exchange	Zero
B	Cooling Tower	Reverse Osmosis	Minimal
C	Cooling Tower	Ion Exchange	Conventional
D	Cooling Tower	Reverse Osmosis	Conventional
E	Air Cooling	Ion Exchange	Zero
F	Air Cooling	Reverse Osmosis	Minimal
G	Air Cooling	Ion Exchange	Conventional
H	Air Cooling	Reverse Osmosis	Conventional

Tables 2a, 2b and 2c

Hydrogen Cost vs. Water Purchase and Discharge Prices for a Baseline System						
		Purchase Price for Water (\$/gal)				
		\$0.0001	\$0.001	\$0.01	\$0.10	\$1.00
Discharge Price for Waste Water (\$/gal)	\$0.0001	\$1.359	\$1.364	\$1.417	\$1.944	\$7.211
	\$0.001	\$1.360	\$1.365	\$1.418	\$1.945	\$7.212
	\$0.01	\$1.372	\$1.377	\$1.430	\$1.956	\$7.224
	\$0.10	\$1.487	\$1.492	\$1.545	\$2.072	\$7.340
	\$1.00	\$2.643	\$2.649	\$2.701	\$3.228	\$8.496

Hydrogen Cost vs. Water Purchase and Discharge Prices for the Most Economic System						
		Purchase Price for Water (\$/gal)				
		\$0.0001	\$0.001	\$0.01	\$0.10	\$1.00
Discharge Price for Waste Water (\$/gal)	\$0.0001	1.359	1.364	1.414	1.668	3.717
	\$0.001	1.360	1.365	1.415	1.669	3.717
	\$0.01	1.372	1.377	1.425	1.678	3.717
	\$0.10	1.487	1.492	1.520	1.773	3.717
	\$1.00	1.957	1.959	1.975	2.133	3.717

Most Economic System vs. Water Purchase and Discharge Prices						
		Purchase Price for Water (\$/gal)				
		\$0.0001	\$0.001	\$0.01	\$0.10	\$1.00
Discharge Price for Waste Water (\$/gal)	\$0.0001	B	B	F	F	E
	\$0.001	B	B	F	F	E
	\$0.01	B	B	F	F	E
	\$0.10	B	B	F	F	E
	\$1.00	E	E	E	E	E